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EEG Spatial Synchronization during Performance of Verbal Operations in Twins

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Abstract

In the present project, monozygotic (N = 102 pairs) and dizygotic (N = 98 pairs) twins participated in EEG registration. Analysis of our data suggests that the contribution of genetic factors to the difference in the degree of synchronization (coherence) of the EEG is different for the selected frequency range (due to their origins), and for different regions of the cortex.

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Keywords: heritability of EEG coherence, twins.

1. Introduction

One of pressing issues today is the question of how genes influence the behavior. Thus on the basis of modern works it is possible to tell with confidence, that such influence is carried out through influence on brain processes. The attention is focused on endophenotypes (intermediate phenotypes), that allows to connect genes and behaviour. It is shown that when the learning algorithm changes the behavior of the neural software changes too [1], [2].

In this paper the features of the spatial organization of the EEG in the performance of verbal operations (verbal-associative activity and arithmetic counting) are considered, persons with different features of the individual profile asymmetry of sensor and motor functions are in the center of our attention. In this case, the use of twin study method allows us to measure the components of the phenotypic variance of the studied traits.

The increase of the degree of rhythmic components of EEG synchronization, assessed through indicators of the coherence function is the conventional indicator of functional interaction of cortical areas. The analysis of

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the coherence function parameters is used to study the morphological and functional organization of the cortex, as in the rest, and in the process of cognitive activity.

Application of coherence analysis for the study of cortical connections is based on the assumption that the coherence between the two EEG signals reflects the functional relationship between the underlying cortical areas. Since the values of the coherence depends on the stability, power and phasic relationships between signals, any factors that affect the covariance of spatially distributed EEG signals must influence the value of coherence.

2. Review of Literature

Gmehlin D. et al. showed that the degree of synchronization of the electrical activity of the brain grows during the school age, reaching the highest values in the alpha range in the left hemisphere [3]. In recent years there has been growing interest in the evaluation of genotype-environmental influences on the degree of synchronization of brain electrical activity, estimated using the coherence function, which is seen as a possible endophenotypes of cognitive functions [4].

G.C.M. Van Baal et al. researched genetic and environmental influences on the cortico-cortical connections and showed that on the 5-year-old twins, a significant part of the change was explained by genetic influences. Estimates of heritability of the coherence of cortico-cortical connections varied from 30 to 71%, the average value of the heritability has made 49 % [5].

In the study of 5-year and 7-year old twins it was found that at the age of five years the average value of the heritability of EEG coherence (frequency range from 0.5 to 30 Hz) is 61% for the left hemisphere and 49% for the right, at the age of seven years is an average of 59% for the left and 62% for the right hemisphere. Authors interpreted these results due to the fact that the genetic influence on the coherence can take many forms. Thus, genetic factors can influence through proteins (for example, through oligodendrosit that forms myelin sheath of nerve fibers), affecting the diameter of the axon, the density of the ion channel, and myelination, or by proteins (e.g., growth factors), affecting various aspects of synaptic connections, such as synaptogenesis, axon outgrowth, increase of existing synaptic terminals [6].

Obtained in Tang Y. et al. estimate the heritability of EEG spectral power is in the range between 0.22 and 0.65 and had higher values for all leads and frequency ranges (from theta (3-7 Hz) to high beta (20-28 Hz)). In the range of the theta frequency higher levels of heritability were obtained for the fronto-central leads. Estimates of heritability in the low-and high-frequency alpha range, and low-frequency beta range were relatively high in the fronto-central regions with an increase in heritability from the central to the parietal and occipital regions. In the mid-range and high-beta in the central region of the cortex heritability estimate is higher than in the same area on the periphery [7].

The purpose of the present investigation was to identify the characteristics of spatial synchronization of brain electrical activity at rest, to evaluate the contribution of genotype and environmental factors in their phenotypic variability.

3. Method

3.1. Participants

In our research 102 monozygotic twins pairs (MZ) at the age from 14 till 26 years (male – 48 pairs, female – 54 pairs), 98 dizygotic twins pairs (DZ) (male – 46 pairs, female – 52 pairs) took part. All examinees without deviations in a state of health, participated in research voluntary. Middle age 18,6 years. For definition zygosity of twins the method of polysimptoms similarities was used; steams with not clear diagnostics did not join to the research.

3.2. Instruments

Record EEG was spent under the international standard 10x20; for recording cerebral waves certificated electroencephalograph «Encefalan», the version «Elite-M» 5.4-10-2.0 manufactured by «Medicom» Taganrog (Russia) was used. Recording was carried out in the isolated room.

3.3. Procedure

EEG data acquisition was performed according to the International 10/20 extended system. Electrical brain activity was recorded with a 21-channel EEG data acquisition system (Fp_z, F_z, C_z, P_z, O_z, Fp_1, Fp_2, F_7, F_3, F_4, F_8, T_3, C_3, C_4, T_4, T_5, P_3, P_4, T_6, O_1, O_2), the monopolar scheme with ipsilateral ear reviewers was applied. The impedance of each electrode was always below 10 kΩ. Filtration EEG was carried out in a range of 0,5-70 Hz. One minute of resting EEG were collected while participants were instructed to relax with their eyes closed. The participants were seated in a comfortable chair in a dark room. It was analyzed resting EEG, and also registered in experimental tests. Sequence of functional tests at record EEG: resting state EEG, «to open eyes», «to close eyes», test «verbal associations» (inventing of words on the letter «a»), test «the account in mind» (consecutive addition of figure 7). For tracing and suppression of EEG artefacts registration of ECG, EMG, EOG were used. The analysis of a spectrum of absolute power was carried out by comparison of indicators of background test with functional in the same frequency ranges (delta (0,5-4 Hz), theta (4-8 Hz), alpha 1 (8-10,5 Hz), alpha 2 (10,5-13 Hz), beta 1 (13-24 Hz), beta 2 (24-35 Hz)ranges. For a profile estimation of lateral organizations the computer program "Profile" was used (Valeology scientific research institute, Russia), allowing to estimate motor, touch and general functional asymmetry.

3.4. Data analysis

To probe the research questions, descriptive statistics, Spearman correlation were calculated using the Statistica 6.0 software.

Dispersive analysis ANOVA for revealing of spectral characteristics EEG at persons with different types of lateralization is carried out. For an estimation of heritability and environmental influences was used: $h^2 = 2$ (r (MZ) - r (DZ)); c^2 = r (M3) - h^2; $e^2 = 1 - h^2 - c^2$, where h^2 - heritability indicator, r(MZ) - intrapair correlation of monozygotic twins; r(DZ)) - intrapair correlation unisex dizygotic twins; c^2 - total environment; e^2 - individual environment.

4. Results and Discussion

Absolute spectral power in the alpha range (8-13 Hz) was in the right and left occipital areas 34,5 ± 16,9 and 33,4 ± 15,9 mkV^2.

By T-Student's test analysis the significance of differences in spectral power of EEG was showed, a significant increase in capacity in the sample «Verbal associations» in comparison with the background is in the range of delta in leads O1 (T = 2,56, p <0,05), P3 (T = 2,88, p <0,05), C3 (T = 2,44, p <0,05), T5 (T = 2,74, p <0,05), Cz (T = 2.49 , PZ (T = 2,24, p <0,05), F7 (T = 3,06, p <0,05), T3 (T = 2,62, p <0,05) (left hemisphere advantage). A sample «Arithmetic account» in the range of delta significant increase in capacity compared to the background is in leads T5 (T = 2,49, p<0,05), T3 (T = 2,47, p <0,05) (represented left hemisphere). A significant increase in capacity compared to the background is in the range theta in leads O2 (T = 2,07, p <0,05), OZ (T = 2,75, p <0,05), P 3 (T = 2.77 , p <0,05), P 4 (T = 3,27, p <0,05), PZ (T = 2,42, p <0,05), T5 (T = 3,14, p <0, 05), T6 (T = 2,26, p <0,05), C3 (T = 2,72, p <0,05), C4 (T = 3,75, p <0,05), Cz (T = 4,85, p <0,05), F7 (T =

3,20, p <0,05), F8 (T = 2,89, p <0,05), T3 (T = 3.05 , p <0,05), F3 (T = 3,40, p <0,05), F4 (T = 3,44, p <0,05), Fz (T = 3,45, p <0, 05).

Data of the classical twins method showes that genotype factors bring the essential contribution in phenotypic variability of manual asymmetry ($h^2 = 0,48$), touch asymmetry (asymmetry of sight $h^2 = 0,46$, asymmetries of hearing $h^2 = 0,32$). The estimation of heritability of type of functional asymmetry has made 0,26, thus the essential contribution in phenotypic variability of the given indicator is brought by the individual environment ($e^2 = 0,74$).

Genotype-environmental determinants of rhythmic components of EEG power in the verbal-associative operations and arithmetic score. Figures 1-3 reflect the results of the evaluation of the contribution of factors of genotype (h^2), total (c^2) and individual (e^2) environment in inter-individual variability of the spectral power of EEG theta, alpha and beta rhythms of resting, and in samples of «Verbal association» and «Arithmetic account». For the assessment of genotype-environmental determinants of EEG spectral power in the performance of verbal associative activity and arithmetic accounts compared with the baseline values when calculating the EEG were selected only the lead, for which values were obtained phenotypic variance components in all three samples.

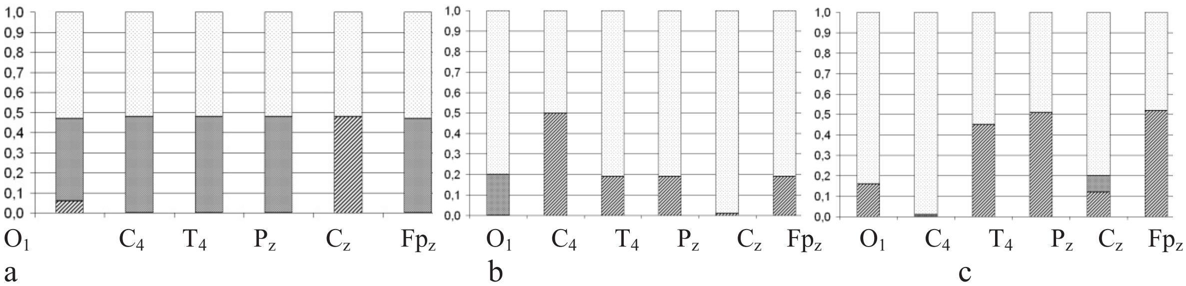

Fig. 1. (a) the contribution of genetic (h^2), total environment (c^2), individual environment (e^2) components of phenotypical dispersion of resting state EEG theta; (b) EEG during the performance of test «Verbal associations»; (c) EEG during the performance test «The account in mind».

EEG theta power during performance of test «Verbal associations» demonstrates a significant decrease in performance heritability of spectral power in the central abduction Cz ($p < 0.01$) and a significant increase in performance of heritability of spectral power in the central ($p < 0.01$) and anterior temporal ($p < 0.05$) and in the area to the right anterior frontal central region ($p < 0.05$) in comparison with resting state EEG. Arithmetic accounts in the central ($p < 0.01$) and anterior temporal ($p < 0.01$) on the right and the areas in front of the anterior-central region ($p < 0.01$) is even more significant increase in performance on the heritability of the spectral power compared with the baseline values (Figure 1).

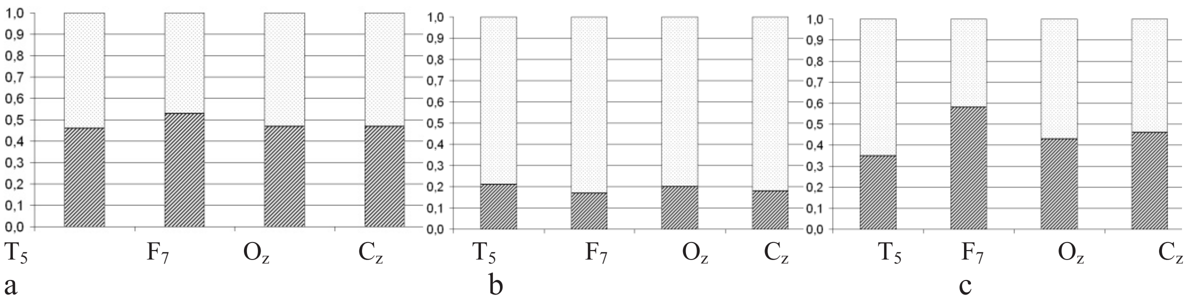

Fig. 2. (a) the contribution of genetic (h^2), total environment (c^2), individual environment (e^2) components of phenotypical dispersion of resting state EEG alpha; (b) EEG during the performance of test «Verbal associations»; (c) EEG during the performance test «The account in mind».

EEG alpha power during performance of test «Verbal associations» in comparison with resting state EEG is a significant reduction of heritability indicator in temporal and frontal areas at the left ($p < 0,05$), in central and occipital areas ($p < 0,05$). At performance of the arithmetic account in the given areas there are no significant distinctions of heritability indicator in comparison with a resting state EEG (Figure 2).

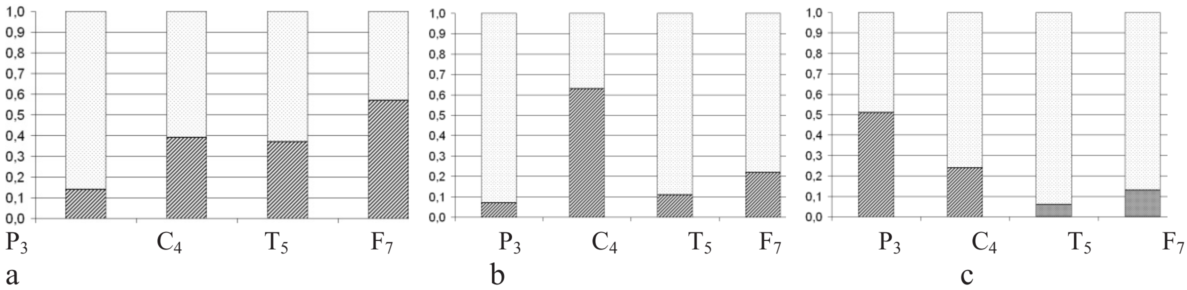

Fig. 3. (a) the contribution of genetic (h^2), total environment (c^2), individual environment (e^2) components of phenotypical dispersion of resting state EEG beta; (b) EEG during the performance of test «Verbal associations»; (c) EEG during the performance test «The account in mind».

EEG beta power during performance of test «Verbal associations» demonstrates a significant reduction of the impact of genotypic factors and the growing role of individual protection factors observed in a posterior-lateral-temporal and left frontal areas ($p < 0.05$) in comparison with resting state EEG. In the right central abduction C4, on the contrary, there was a significant increase in the influence of genotypic factors ($p < 0.05$). Arithmetic account is a significant increase in performance of heritability of spectral power compared to the background values observed in the left parietal region ($p < 0.01$), thus there is a significant decrease in the indices of heritability of spectral power in the posterior-temporal ($p < 0.05$) and lateral-frontal areas of the left ($p < 0.01$) (Figure 3).

Of resting state EEG recordings were allocated plots duration 1000 ms, for which we obtain the estimate of the coherence of each of the 21 registered with all the remaining leads, taking into consideration the frequency ranges. The resulting estimates were averaged coherence for monozygotic and dizygotic twins.

The averaged values of the index of heritability coherence of electrical activity to occipital, parietal, central, temporal, and anterior frontal regions for each of the six allocated frequency bands are shown in Table 1.

Table 1. The value of the heritability of EEG coherence

Frequency range	Leads									
	O1	O2	P3	P4	C3	C4	T3	T4	Fp1	Fp2
delta	0,34	0,32	0,30	0,31	0,19	0,24	0,15	0,31	0,32	0,11
theta	0,14	0,14	0,15	0,31	0,13	0,22	0,13	0,23	0,14	0,03
alpha 1	0,15	0,13	0,13	0,05	0,08	0,16	0,07	0,28	0,37	0,29
alpha 2	0,15	0,10	0,08	0,19	0,12	0,18	0,12	0,09	0,20	0,17
beta 1	0,20	0,21	0,27	0,28	0,19	0,19	0,14	0,19	0,35	0,10
beta 2	0,05	0,14	0,08	0,06	0,06	0,10	0,14	0,02	0,08	0,19

5. Conclusion

The analysis of our data showed that performance of verbal operations is connected with change of values of heritability of EEG spectral power predominantly in the left hemisphere. In the beta range at performance of verbal operations changes the ratio of genotype-environmental factors, and the observed decrease in rate of heritability beta EEG spectral power in the central range of the frontal and temporal region to the left, as well as increasing the rate in the central region on the right. At performance of verbal operations increase in the heritability of spectral power theta, as well as reducing the corresponding figure for the theta range in the temporal, frontal and central and occipital areas with the advantage of left hemisphere were observed.

Analysis of our data suggests that the contribution of genetic factors to the difference in the degree of synchronization (coherence) of the EEG is different for the selected frequency range (due to their origins), and for different regions of the cortex.

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